

# An Open-Source Tool for Automated Generation of Black-box xUnit Test Code and its Industrial Evaluation

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# Talk Outline

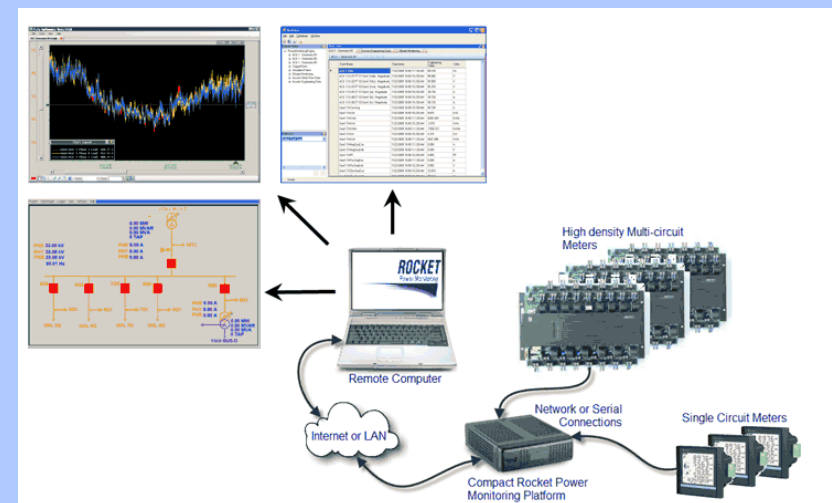
- **Context - Company and the System Under Test**
- **Units Under Test (Goal: Unit Testing)**
- **Black-box Unit Testing (BBUT)**
- **The Automated BBUT Tool**
- **Evaluation in an Industrial Setting**
- **Effectiveness in Detecting Defects**
- **Conclusions**
- **Q/A**

# Context - Company and the System Under Test

- A commercial large-scale Supervisory Control and Data Acquisition (SCADA) software system
- Is called *Rocket*
- Has been developed using Microsoft Visual Studio C#
- A total development effort of about 6 man-years.
- Developed using the iterative development process (but not strictly Agile)
- Has now been deployed in several pilot projects and it is well-accepted by the clients.

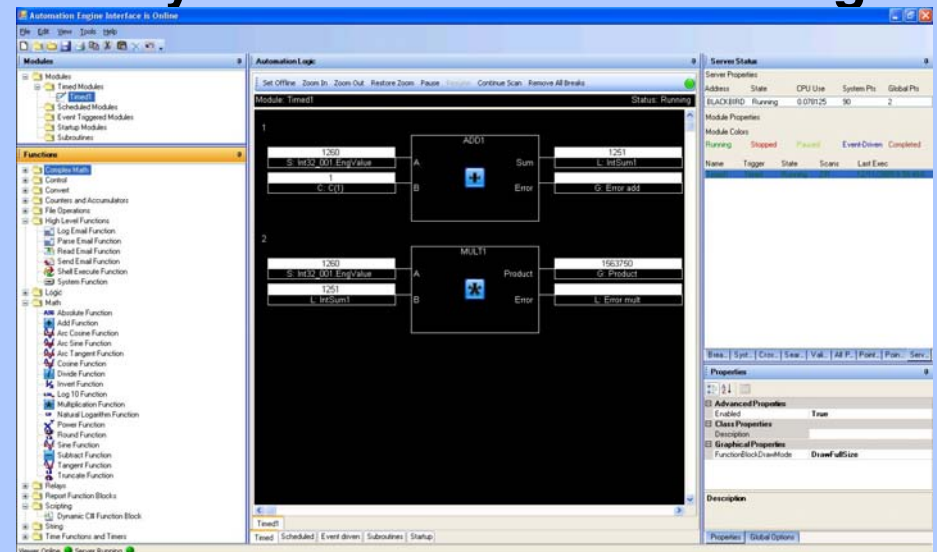


**MR Control Systems**  
INTERNATIONAL INC



# Context - Company and the System Under Test

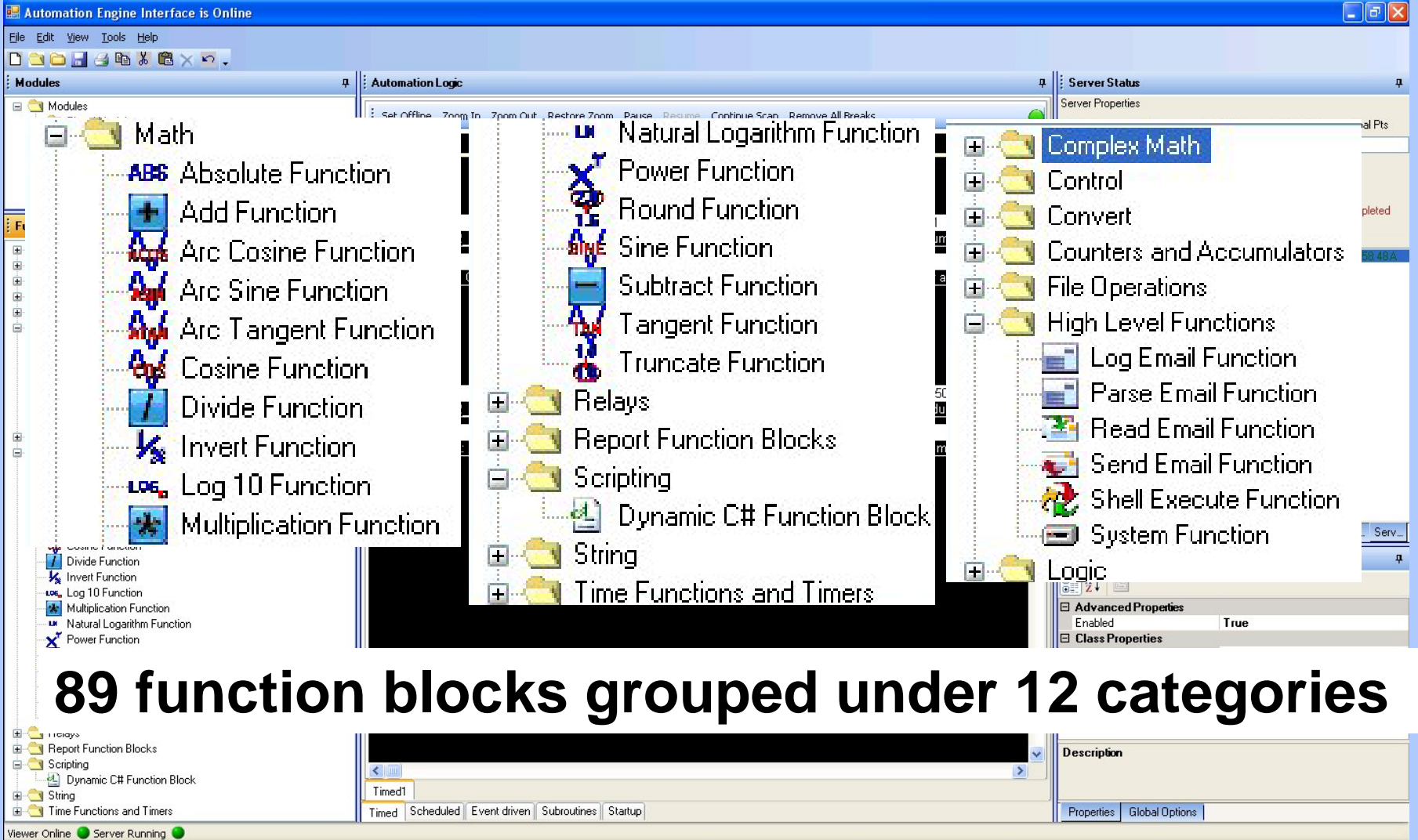
- The SUT has only been tested manually during iterations of the development.
- Towards the end of the project, importance of automated testing was felt
- Thus, a collaboration among the authors
- Our goal: to conduct automated and systematic software testing on the entire Rocket platform.
- Meetings between the project stakeholders
- and prioritizing the modules
- we agreed the first system module to be tested is the *Automation Engine*.



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# Units Under Test (Goal: Unit Testing)



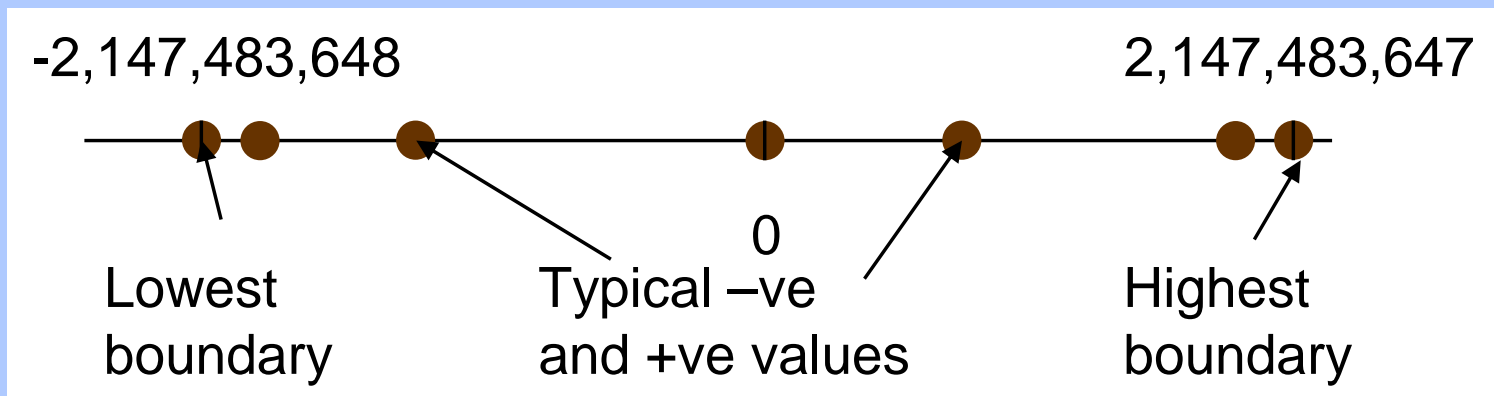
The screenshot displays the Automation Engine Interface with a tree view of function blocks. The categories and their contents are as follows:

- Math**
  - Absolute Function
  - Add Function
  - Arc Cosine Function
  - Arc Sine Function
  - Arc Tangent Function
  - Cosine Function
  - Divide Function
  - Invert Function
  - Log 10 Function
  - Multiplication Function
- Complex Math**
- Control**
- Convert**
- Counters and Accumulators**
- File Operations**
- High Level Functions**
  - Log Email Function
  - Parse Email Function
  - Read Email Function
  - Send Email Function
  - Shell Execute Function
  - System Function
- Logic**
- Natural Logarithm Function**
- Power Function**
- Round Function**
- Sine Function**
- Subtract Function**
- Tangent Function**
- Truncate Function**
- Relays**
- Report Function Blocks**
- Scripting**
- Dynamic C# Function Block**
- String**
- Time Functions and Timers**

**89 function blocks grouped under 12 categories**

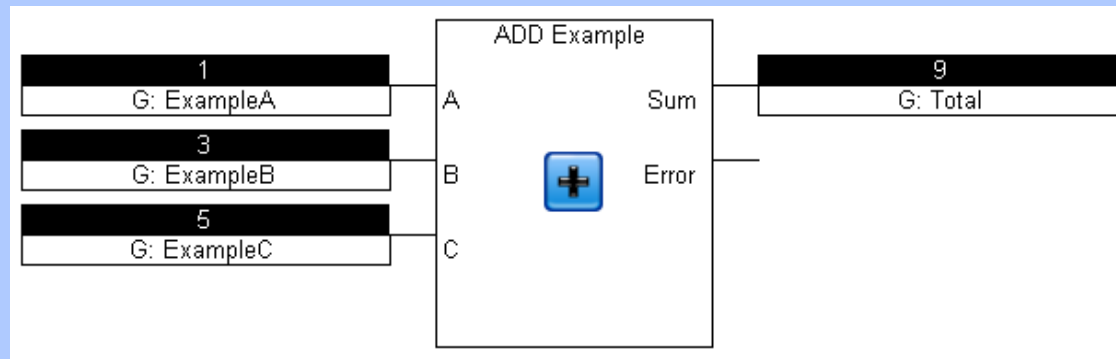
# Black-box Unit Testing (BBUT)

| Equivalence classes of a 32-bit integer |   |
|---|---|
| 1. Nominal positive values              | 5. Minimum 32-bit integer                             |
| 2. Nominal negative values              | 6 .The integer just before the maximum 32-bit integer |
| 3. The value of 0                       | 7. The integer just after the minimum 32-bit integer  |
| 4. Maximum 32-bit integer               |   |



# Black-box Unit Testing (BBUT): Challenges

- **The Add function block**

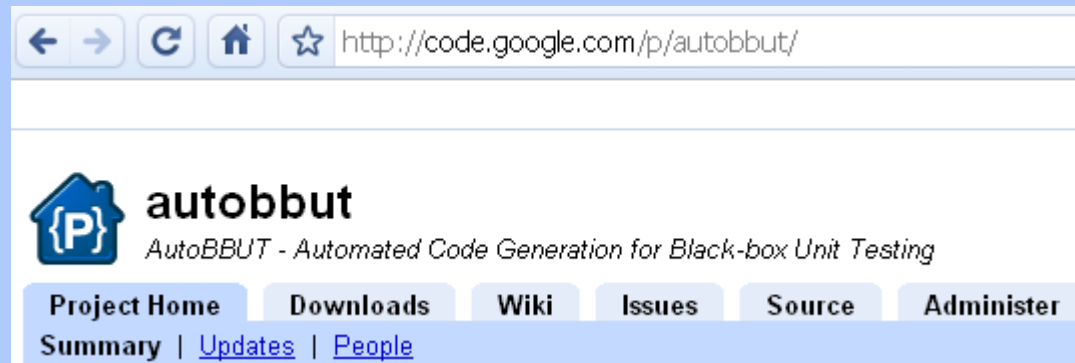


- If we apply the equivalence classing, we will get 19,683 test cases for only this function block. Bad news ;(
- **Challenge 1:** Coding of test cases (in NUnit): Too much effort
- **Challenge 2:** Coupling of test cases to test input data
- **Challenge 3:** Generation of test oracle

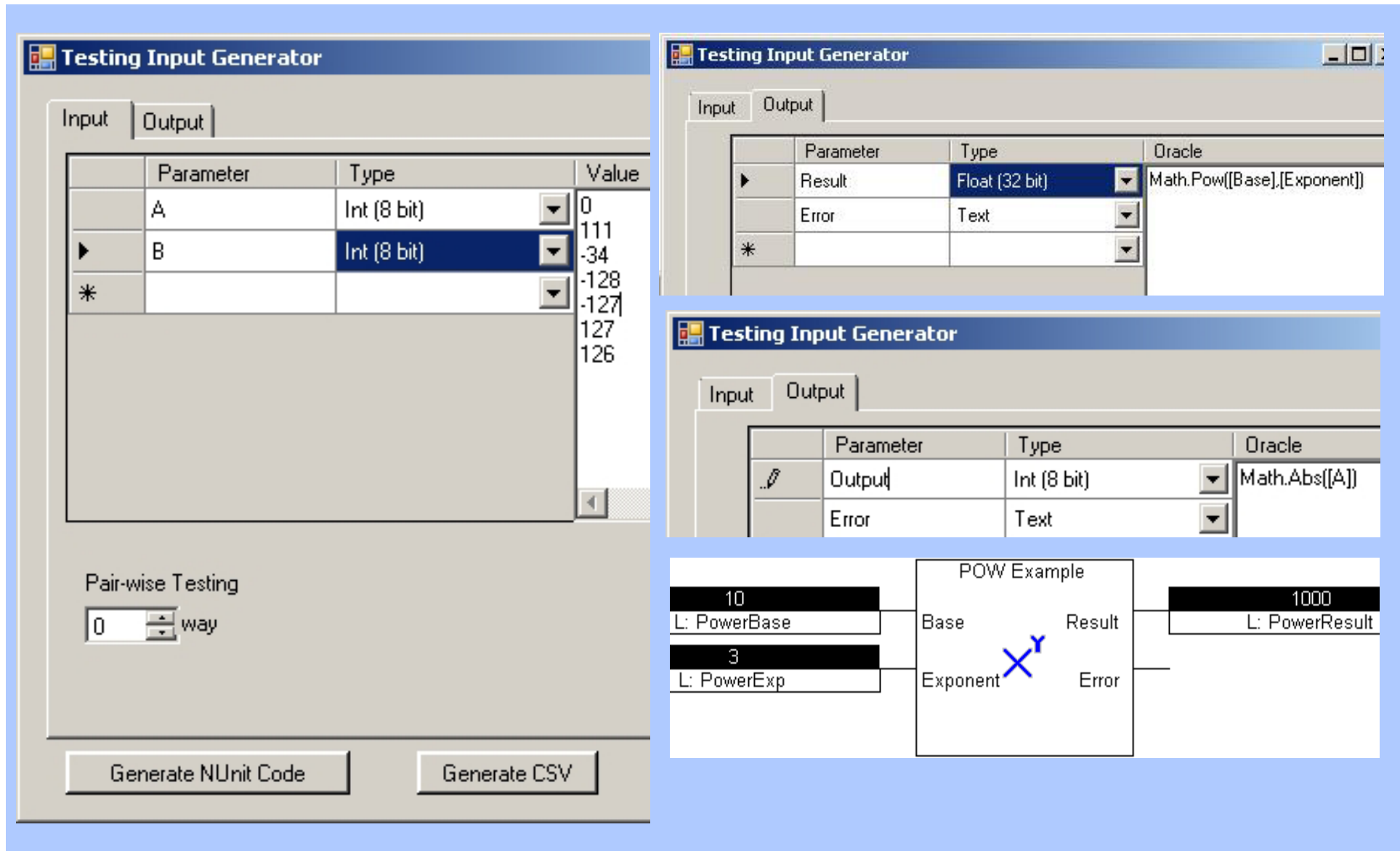


# Black-box Unit Testing (BBUT): Challenges

- **One possible solution → Automated generation of NUnit test code**
- **There are some tools out there:**
  - Microsoft Pex, JML-JUnit, JUB (JUnit test case Builder), TestGen4J, JCrasher, NModel
- **We evaluated those tools for our purpose, but unfortunately, none was suitable (details I the paper)**
- **Decision: to implement our own tool**



# AutoBBUT - GUI and Features



The image displays three screenshots of the AutoBBUT Testing Input Generator GUI, illustrating its configuration and output generation capabilities.

**Top Left Screenshot:** Shows the 'Input' tab with a table of parameters. Parameter B is selected.

| Parameter | Type        | Value |
|-----------|-------------|-------|
| A         | Int (8 bit) | 0     |
| B         | Int (8 bit) | 111   |
| *         |             | -34   |
|           |             | -128  |
|           |             | -127  |
|           |             | 127   |
|           |             | 126   |

Below the table, 'Pair-wise Testing' is set to '0 way'. Buttons for 'Generate NUnit Code' and 'Generate CSV' are visible at the bottom.

**Top Right Screenshot:** Shows the 'Output' tab with an Oracle definition table.

| Parameter | Type           | Oracle                      |
|-----------|----------------|-----------------------------|
| Result    | Float (32 bit) | Math.Pow([Base],[Exponent]) |
| Error     | Text           |                             |
| *         |                |                             |

**Bottom Screenshot:** Shows the 'Output' tab with a test case table and a diagram.

| Parameter | Type        | Oracle        |
|-----------|-------------|---------------|
| Output    | Int (8 bit) | Math.Abs([A]) |
| Error     | Text        |               |

The diagram below shows a 'POW Example' block with inputs 'Base' (value 10, L: PowerBase) and 'Exponent' (value 3, L: PowerExp). The outputs are 'Result' (value 1000, L: PowerResult) and 'Error'. A blue 'X' is drawn over the 'Exponent' input and 'Error' output.

# AutoBBUT - Example Usage

```
TestProject.PowerFBTest Test61642af496604639a6bc3223c659c542()
[TestMethod]
public void Test61642af496604639a6bc3223c659c542 ()
{
    TD.setInputParameter(FunctionBlockName, "Base", "Int (8 bit)", "-128");
    TD.setInputParameter(FunctionBlockName, "Exponent", "Int (8 bit)", "-128");

    RocketParameter resultParam = TD.setOutputParameter(FunctionBlockName, "Result", "Float (32 bit)");
    RocketParameter errorParam = TD.setOutputParameter(FunctionBlockName, "Error", "Text");

    TD.execute(FunctionBlock, FunctionBlockName);

    Assert.AreEqual(float.Parse("1.8929E-270"), float.Parse(TD.getOutputByName(resultParam.PointName)), 0.0001);
    Assert.AreEqual("", TD.getOutputByName(errorParam.PointName));
}

[TestMethod]
public void Test6e134866ed144f3d9c2370bc20cda45f ()
{
    TD.setInputParameter(FunctionBlockName, "Base", "Int (8 bit)", "-127");
    TD.setInputParameter(FunctionBlockName, "Exponent", "Int (8 bit)", "-127");

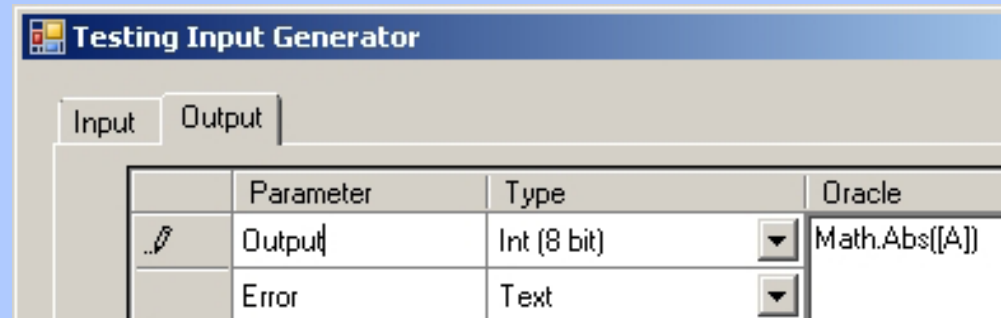
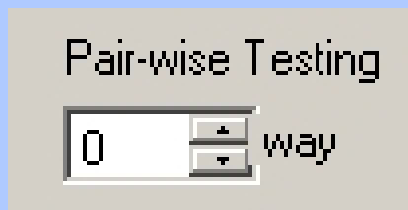
    RocketParameter resultParam = TD.setOutputParameter(FunctionBlockName, "Result", "Float (32 bit)");
    RocketParameter errorParam = TD.setOutputParameter(FunctionBlockName, "Error", "Text");

    TD.execute(FunctionBlock, FunctionBlockName);

    Assert.AreEqual(float.Parse("-6.5604E-268"), float.Parse(TD.getOutputByName(resultParam.PointName)), 0.0001);
    Assert.AreEqual("", TD.getOutputByName(errorParam.PointName));
}
```

## AutoBBUT – Technologies (Libraries) used

- To generate all the n-way test cases, we used a recently-introduced Test API from Microsoft, called `Microsoft.Test.VariationGeneration`.



- For the development of automated test oracle generation, we used a utility available in the .NET framework class library, called `System.CodeDom.Compiler`.
- **CodeDOM: Code Document Object Model**

# AutoBBUT - Development Details

- Developed in C# .Net platform. Consists of 875 LOC.

InputGenerator.TestInputGenerator



generateTestSuiteCode()

```
// loop over all pairwise test cases
foreach (Variation v in combinatoryModel.GenerateVariations(pairwise_way, 1234))
{
    inputList = new Dictionary<string, RocketParameter>();
    Guid guid = Guid.NewGuid();
    // remove -'s from the random string
    string guidstring = Regex.Replace(guid.ToString(), "-", "");
    // start generating the test method one by one
    testSuiteCode += "[TestMethod]" + Environment.NewLine;
    // test method signature
    testSuiteCode += "public void Test" + guidstring + "()" +
        Environment.NewLine + "{" + Environment.NewLine;

    // feeding the input parameters in to the test code
    foreach (Parameter param in combinatoryModel.Parameters)
    {
        RocketParameter input = new RocketParameter();
        testSuiteCode += "TD.setInputParameter(FunctionBlockName,\"\" + input.Name + "\", \"\" +
            input.Type + "\", \"\" + input.Value + "\" );" + Environment.NewLine;
        inputList.Add(input.Name, input);
    }
    testSuiteCode += Environment.NewLine;

    // feeding the output parameters in to the test code
    foreach (DataGridViewRow outputRow in outputGridView.Rows)
```

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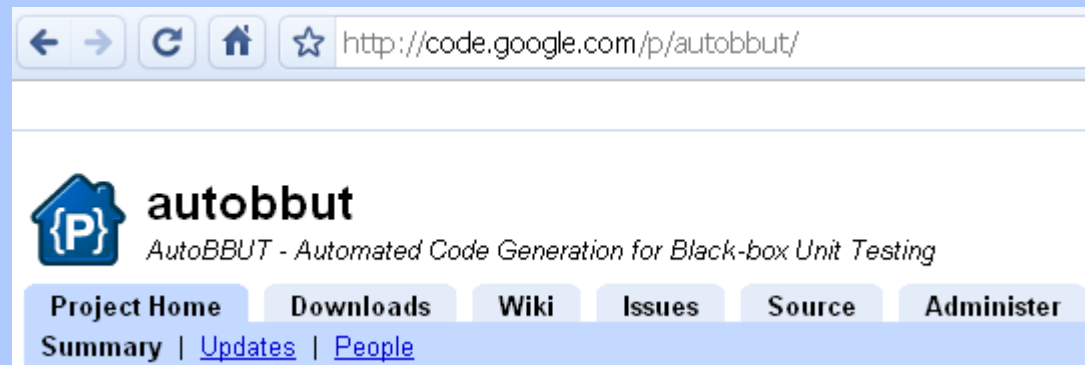
# Evaluation in an Industrial Setting

- Only 57 function blocks of 89 function blocks were final in terms of their requirements at this time
- We generated 1,962 NUnit test cases for automated black-box unit testing of 58 function blocks
- The total size of the NUnit test suite is currently 15,906 test LOC.
- Since test case code is automatically generated, each test case method is  $8 \pm 2$  LOC

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    RocketParameter resultParam = TD.setOutputParameter(FunctionBlockName, "Result", "Float (32 bit)");  
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    Assert.AreEqual("", TD.getOutputByName(errorParam.PointName));  
}
```

# Conclusions

- **An email from the MRCSI's CEO:**
  - *“Many thanks for your efforts. I reviewed your [defect] report. It looks complete and clear. I and am very pleased with the results. We will include all identified bugs to the list and will try to address them.”*



- **Open source**
- **A lot of effort has been spent to have a clean design for it which makes it easily extensible and adaptable to other platforms (e.g., JUnit) and SUTs by other testers.**



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